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## RESEARCH ARTICLE

# Attention profiles following preterm birth: A review of methods and findings from infancy to adulthood

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## Abstract

Children born preterm are at increased risk for attention deficit hyperactivity disorder (ADHD) and subclinical attention problems. The ADHD profile that presents following prematurity has been characterized by inattention without impulsivity or hyperactivity. This supports the existence of a preterm attentional phenotype. This review aims to examine the preterm attentional profile regarding three attention networks: alerting, orienting, and executive attention, and to survey the methods used for measuring attention networks. We conclude that prematurity is associated with impairments in the attention networks, but a robust and detailed articulation of a distinctive preterm attention phenotype cannot be ascertained from the available data. Future research should focus on addressing methodological challenges associated with measuring attention, protocol harmonization, open data sharing, and longitudinal studies

**Abbreviations:** ADHD, attention deficit hyperactivity disorder; ANT, attention network test; BRIEF, behaviour rating inventory of executive function; ECBCQ, early childhood behaviour questionnaire; GA, gestational age; Leiter-R, Leiter International Performance Scale-Revised; SART, sustained attention to response task; TAP, tests of attentional performance; TEA-Ch, test of everyday attention for children; TOVA, test of variables of attention.

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utilizing a variety of measurement types. Delineating the developmental trajectory of attention will improve understanding of the pathway from prematurity to attentional problems including ADHD and guide interventions.

#### KEYWORDS

ADHD, attention, attention networks, development, preterm birth

#### Highlights

- We review the literature measuring associations between preterm birth and altered development of the attention networks.
- Attention is impaired but inconsistencies and methodological issues limit the conclusions that can be drawn about the preterm attentional phenotype.
- Highly powered, longitudinal studies using a range of carefully considered measurement types are needed.

## 1 | INTRODUCTION

Attention is the ability to direct neurocognitive resources towards a stimulus, or stimulus feature in order to support further processing of a target which may require action (Atkinson & Braddick, 2012). It allows for the disengagement of resources away from previously attended stimuli and for the maintenance of concentration required for the completion of demanding tasks. Thus, attention supports efficient assessment of the environment and allows for the planning and execution of optimal behavioural responses.

Optimal development of the attention system supports later development of higher-order cognitive processes such as social cognition, information processing, goal setting, and cognitive flexibility (Anderson, 2002; De Schuymer, De Groote, Desoete, & Roeyers, 2012). Conversely, suboptimal attentional development in infancy has been associated with problems with social interactions and academic attainment during childhood and adolescence (Spira & Fischel, 2005).

One population for whom this is of particular relevance is infants and children who have been born preterm (<36 completed weeks of gestation). Preterm infants are at risk for widespread cognitive impairment including problems with attention (Johnson & Marlow, 2016). Due to the hierarchical and reciprocal nature of the development of cognitive abilities (Fischer, 1980; Stuss, 1992), and relative early development of attention compared to other skills (Ruff & Rothbart, 2001), impaired attention may represent early underpinnings of the more widespread cognitive delays reported in the preterm population (Johnson & Marlow, 2016; Marlow, 2004) and therefore may be useful as a proxy measure for general cognitive abilities. Furthermore, attention has been shown to predict later academic attainment in preterm children (Jaekel, Wolke, & Bartmann, 2013; Johnson, Wolke, Hennessy, & Marlow, 2011) and as such is an important early indicator of later outcomes in this population.

Children born preterm have a higher likelihood of being diagnosed with attention deficit hyperactivity disorder (ADHD; Franz et al., 2018; Johnson & Marlow, 2016; Mulder, Pitchford, Hagger, & Marlow, 2009). The behavioural presentation of ADHD within this population is more commonly associated with inattentive compared to hyperactive/impulsive symptoms and a greater likelihood of being diagnosed with the ADHD-Inattentive subtype (Franz et al., 2018; Jaekel et al., 2013; Johnson et al., 2010, 2016; Johnson & Wolke, 2013). ADHD in preterm children has been found to relate to neonatal comorbidities (Johnson & Marlow, 2011) and perinatal clinical risk related to

prematurity (Montagna et al., 2020). Conditions that commonly co-occur with ADHD in non-preterm populations are less common and the greater prevalence in males that is typically reported in non-preterm samples is absent (Johnson & Marlow, 2011). These distinctions provide support for the existence of a preterm attentional phenotype. Further understanding of the exact nature of attention problems in preterm children will inform clinical and diagnostic practice.

Evidence from intervention studies which report improvement in features of attention provide further support for the need to identify and delineate specific attention impairments in preterm children (Gould et al., 2018; Nordhov, Rønning, Ulvund, Dahl, & Kaaresen, 2012; Welch et al., 2015). Identifying precise areas of impairment will facilitate the design of interventions specifically targeting these weaknesses and thus increasing the potential to yield improvement.

Several longitudinal cohort studies which include children with a history of extremely or very preterm birth (<32 weeks of gestation) report the presence of general attention impairment from childhood through to early adulthood (Breeman, Jaekel, Baumann, Bartmann, & Wolke, 2016; Jaekel et al., 2013; Linsell et al., 2018). The stability of attention difficulties across the life span indicates that early assessment of attention may have value for predicting later outcome. Although cohort studies of this nature tell us a great deal about general attention abilities, they do not address early attention impairments that may be detectable during infancy and fail to differentiate between attention networks.

## 1.1 | Attention networks

Evidence from neuropsychological, neuroimaging, and functional neuroanatomy studies suggest that the attention system is made up of several distinct yet interconnected networks (Fan, McCandliss, Fossella, Flombaum, & Posner, 2005; Fan, McCandliss, Sommer, Raz, & Posner, 2002; Mirsky, Anthony, Duncan, Ahearn, & Keilam, 1991; Mullane, Lawrence, Corkum, Klein, & McLaughlin, 2016; Posner & Petersen, 1990; Xuan et al., 2016). The central theoretical model, proposed by Posner and Petersen (1990), used data inferred from studies of functional neuroanatomy in humans and monkeys to identify three attention networks, which are anatomically and functionally interrelated yet independent. These three networks are proposed to carry out distinct functions: maintaining an alert state, orienting to sensory events, and detecting signals for conscious processing. Here we will refer to these networks as the alerting, orienting, and executive attention networks respectively.

Differences in the developmental trajectories of these networks provide further evidence for their independence. Colombo (2001) describes three important periods in the postnatal development of attention. The first is a period from term to 2 months, during which infants become alert. The second is from 2 or 3 to 6 months of age, when orienting abilities develop. And finally, from 5 to 6 months onwards the executive attention system begins to emerge.

The alerting network is required for the maintenance of a vigilant state, allowing for sustained and focused attention, and rapid stimulus response (Petersen & Posner, 2012; Posner & Petersen, 1990). Alerting emerges relatively early in development, within the first two postnatal months (Colombo, 2001; Reynolds & Romano, 2016). From around 7 months, the ability to sustain attention for longer periods increases due to emerging control exerted by the executive attention system. The ability to maintain an alert state depends on the norepinephrine pathways arising in the locus coeruleus along with a right hemisphere network of frontal, parietal, and temporal cortical and subcortical regions including the anterior cingulate gyrus, dorsolateral prefrontal cortex, and thalamus. (Colombo, 2001; Fan et al., 2005; Petersen & Posner, 2012; Posner & Petersen, 1990; Sturm & Willmes, 2001; Xuan et al., 2016).

The orienting network is concerned with movement of attention towards a target of interest. This system also controls the disengagement of attention, allowing attention to be shifted towards a new stimulus or stimulus feature (Petersen & Posner, 2012; Posner & Petersen, 1990). In typical development, orienting skills emerge within the first 6 months of life (Colombo, 2001). Even new-borns are selective in their attention although they can have difficulty

disengaging from a stimulus. This skill develops rapidly between 2 and 4 months of age (Hood et al., 1996). Anatomically, these functions are supported by a network of parietal, frontal, cortical, and subcortical regions including the right superior parietal cortex, temporoparietal junction, frontal eye fields, and cholinergic systems arising in the basal forebrain (Coull, 1998; Fan et al., 2005; Petersen & Posner, 2012; Posner & Petersen, 1990; Xuan et al., 2016).

Finally, the executive attention network, is responsible for the selection of information for further processing. This network also allows for the inhibition of distraction and the ability to divide attention simultaneously between two or more targets (Petersen & Posner, 2012; Posner & Petersen, 1990). This network is the last to mature and although it begins to emerge within the first postnatal year, it undergoes a dramatic period of development between 18 and 24 months when the frontal cortex also experiences a phase of rapid growth (Reynolds & Romano, 2016; Ruff & Rothbart, 2001). Over the preschool years, development of the executive attention network allows for greater control over lower-level attentional processes, facilitating maintenance, and focus of attention even in contexts that are not intrinsically interesting or where distractors are present. A frontoparietal network including the anterior cingulate cortex, frontal eye fields, intraparietal sulcus, and the cerebellum are involved in the operation of the executive attention network (Colombo, 2001; Fan et al., 2005; Petersen & Posner, 2012; Posner & Petersen, 1990; Xuan et al., 2016).

Various subcomponents of the attention networks have been described in the literature (Kovshoff, Iarocci, Shore, & Burack, 2015; Ristic & Enns, 2015). These subcomponents attempt to describe more specific skills but have not been neuroanatomically delineated to the same degree as the broader networks (alerting, orienting, executive attention) and so their classification is open to some degree of interpretation. In some cases, a number of terms are used for the same processes for example, sustained attention and focused attention are used interchangeably with alerting. In other cases, the same word is used to describe different processes. For example, 'shifting' has been used to describe the process of moving attention towards a target (orienting) or shifting between two tasks (an executive skill). Table 1 lists each component that has been tested by one or more of the studies reviewed below, along with its network categorization. While more fine-grained labels are useful when a specific skill is of interest, due to the interconnection between networks, few tasks will rely on a single subcomponent or network. This overlap and subsequent difficulty in identifying which of these attentional processes (and other cognitive processes) underpin specific measures and tasks as well as a lack of standardization of the labels used to describe these processes poses a very significant challenge when selecting and interpreting this literature.

A more detailed understanding of the presentation of the attention networks in the preterm population would improve knowledge pertaining to the characterization of the preterm attention phenotype, facilitating the design of intervention studies and ultimately more targeted clinical care. Early identification of problems with known associations with specific outcomes will aid in mapping developmental trajectories, including onset and manifestation of ADHD. In addition, early identification of specific attentional impairment in preterm infants may be valuable for stratifying infants for trials of interventions designed to improve long-term outcome. In the future, interventions will be facilitated by a more detailed knowledge of risk, resilience, and mechanisms of change.

## 1.2 | Previous reviews

Reviews by Mulder et al. (2009) and van de Weijer-Bergsma, Wijnroks, and Jongmans (2008) shed some light on the question of the preterm attention profile. Van de Weijer-Bergsma et al. (2008) conducted a narrative review of studies of attention in preterm born infants and toddlers published between 1980 and 2007. Findings were categorized based on the Attention Network Theory (Petersen & Posner, 2012; Posner & Petersen, 1990). The review concluded that alerting, orienting, and executive attention are impaired in preterm infants, and that problems become more apparent and congruency between studies improves as children get older. The authors note greater agreement between studies on orienting compared to alerting or executive attention. They point out a unique pattern of errors on executive attention tasks in preterm samples and suggest that attention problems in preterm samples differ from

**TABLE 1** Attention subcomponents grouped by attention network: function, and list of tasks that measure this component

Network	Function	Task/measure
Alerting	Maintaining an alert state when engaged with a stimulus	ANT (alerting), TEA-Ch (score!), eye-tracking (UTATE, alerting)
Sustained attention	Maintaining an alert state when engaged with a stimulus or task	TEA-Ch (score!/walk, do not walk), TOVA, Leiter-R, CANTAB (rapid visual information processing), SART
Focused attention	Maintaining an alert state when engaged with a stimulus or task	Eye-tracking, observation, ECBQ (attention focusing)
Orienting	Orienting to sensory stimuli	ANT (orienting)
Shifting	Moving attention towards a stimulus	TAP-C, TEA-Ch (creature counting/opposite worlds), eye-tracking (non-competition/competition paradigm), ECBQ (attention shifting)
Disengagement	Moving attention away from a previously attended stimulus	Eye-tracking (UTATE, disengagement)
Selective attention	Orienting attention towards a stimulus among distractors	TEA-Ch (map Mission)
Executive attention	Detecting stimuli for conscious processing	ANT (executive attention)
Inhibition	Inhibiting responses to specific stimuli in order to attend to another	TEA-CH (walk, do not walk), BRIEF-P (inhibition), eye-tracking (attention control paradigm), A not B task, raisin game
Attention control	Controlling attention when switching between tasks	TEA-Ch (opposite worlds)
Divided attention	The ability to deploy attentional resources to more than one stimulus at a time	TEA-Ch (sky search dual task)

*Note:* Components and tasks are those included in one or more of the studies reviewed here and are not necessarily exhaustive. Where appropriate, task subtests are specified withing brackets.

Abbreviations: ANT = Attention Network Task; BRIEF-P = Behaviour Rating Inventory of Executive Function, Preschool Version; CANTAB = Cambridge Neuropsychological Test Automated Battery; ECBQ = Early Childhood Behaviour Questionnaire; Leiter-R = Leiter International Performance Scale-Revised; SART = Sustained Attention to Response Task; TAP-C = Tests of Attentional Performance for Children; TEA-Ch = Test of Everyday Attention for Children; TOVA = Test of Variables of Attention; UTATE = Utrecht Tasks of Attention in Toddlers.

those in other populations. Relationships between attention and several biological and environmental factors were examined (e.g., medical risk, maternal IQ, socioeconomic status). It was concluded that there are associations and that these factors interact with one another in a complex manner.

Mulder et al. (2009) conducted a review and metanalysis including studies of attention and executive function in children and adolescents born preterm published between 1990 and 2008. Although categorizations were not based directly on the Attention Network Theory, studies were categorized into those measuring sustained attention (a subcomponent of alerting), selective attention (a type of orienting), and inhibition (a form of executive attention). Mulder and colleagues found that although attention impairments were widely reported, results were inconsistent with effect sizes ranging from non-significant to large. They conclude that attention is influenced by age at assessment, gestational age, and task type. The authors highlight the importance of taking methodical differences into

consideration when comparing studies using different tasks and note the dearth of tasks that are pure measures of independent cognitive skills.

### 1.3 | The current review

Substantial advances in medical care within the last 10 years, along with innovations in methodological strategies for the measurement of cognitive abilities (e.g., eye-tracking) warrant an updated review of this literature. Previous reviews focused on studies that measured attention using standardized assessments that measure attention as a function of speed or accuracy on a computerized or pen and paper task. They also included some observational studies of infant attentional behaviours. Neither examined informant reports or eye-tracking measures of attention. Eye-tracking is an objective and non-invasive tool widely used to directly measure looking behaviour as a reflection of perceptual and cognitive processes. The application of eye-tracking technology is therefore useful for the assessment of attention during infancy (Gredebäck, Johnson, & von Hofsten, 2009). The objectivity and precision provided by eye-tracking along with its suitability for measuring attention even in very young infants may provide valuable new insights. Given the frequency with which parent report measures are used to measure ADHD symptoms, we consider questionnaires an important format to include here also.

The current review aims to build upon findings from previous reviews by categorizing studies not only by attention network but also by measurement method. In addition, we include studies utilizing measurement formats not included in previous reviews (i.e., eye-tracking and informant report). We aim to characterize the preterm attention profile in relation to the three networks described, and to survey the range of methods used for exploration of these specific attention networks.

This review was framed around the Attention Network Theory (Petersen & Posner, 2012; Posner & Petersen, 1990) as it aligns with our aim to delineate in greater detail the preterm attentional profile. It allows for the examination of attention as a set of distinct functions (i.e., alerting, orienting, executive attention) rather than one integrated process and thus identify areas of relative weakness. Since previous reviews of this topic have used the same or similar categorizations (Mulder et al., 2009; van de Weijer-Bergsma et al., 2008) adopting the same model allows for clear comparison of the updated literature presented here with that presented in previous reviews. In addition, these categorizations have been adopted by several tasks commonly used to measure attention.

We will consider each network in turn, while categorizing studies by the following commonly used psychological measures: standardized assessment, observation, eye-tracking, or questionnaire. In this way we aim to (a) identify the areas of attention most commonly impaired and (b) provide an overview of available methods for identifying deficits.

## 2 | METHOD

Studies were chosen for inclusion if they measured alerting, orienting, or executive attention using the described psychological measures, (eye-tracking, observation, standardized assessment, or questionnaire) during infancy, childhood, adolescence, or adulthood, were published within the last 10 years and included a preterm group and a term control group. Prematurity was defined as birth before 37 weeks of gestation. Studies including functional or structural neuroimaging methods were excluded as a comprehensive review of the neuroimaging literature would merit an independent piece of work beyond the scope of this review.

Older studies were not included for several reasons. First, this literature has been reviewed previously in two reviews including studies from the 1980s to late 2000s (findings are summarized in Section 1.2 above). Second, advances in neonatal care have meant that infants can survive from earlier gestational ages (Patel, Rysavy, Bell, & Tyson, 2017). Earlier gestational age (GA) is associated with more long-term consequences including increased risk

of cognitive impairment (Blencowe et al., 2013; Myrhaug, Brurberg, Hov, & Markestad, 2019) meaning newer cohorts are more likely to include infants with more substantial impairments. Findings from more recent studies will most closely reflect the attention profile of, and therefore be relevant to, the contemporary preterm population. Finally, recent advancements in the measurement of attention (outlined in Section 1.3) means that methodological recommendations arising from a review of recent studies will be of most value to current and future research.

A search of titles and abstracts was conducted in the PsychInfo database using key words; 'attention', 'attention networks', 'alerting', 'orienting', 'executive attention', 'preterm', 'premature', 'prematurity'. Reference lists of returned texts were manually searched and the 'cited by' function in the Google Scholar database was used to search for additional relevant studies.

### 3 | ALERTING

Table 2 summarizes findings for studies that measured alerting, highlighting only key results in terms of whether there were statistically significant group differences, regardless of variable (e.g., accuracy, reaction time).

#### 3.1 | Eye-tracking

Two eye-tracking studies examined infant alerting and both report significant differences between preterm and term groups. de Jong et al. (2015) examined alerting skills in moderately-to-late born preterm infants at 18 months using an auditory cueing task. They found poorer alerting in the preterm group as demonstrated by a lower mean dwell time on the target. Similarly, Downes et al. (2018) reported poorer focused attention in the form of shorter target fixation duration in the preterm group at 12 months.

#### 3.2 | Observational measures

Reuner et al. (2015) found no difference between preterm and term born infants in time spent attending towards the target object during a toy exploration task at 7 months. The task required the maintenance of an alert state in order to sustain interest in the toy for a period of time (infants were given 20s of exploration time with each toy). However, there were significant differences between extremely/very preterm (E/VPT) and moderate-to-late preterm (MLPT) groups where E/VPT infants spent less time engaging in intense looking or manipulation of the objects (termed focused attention) than MLPT infants. These results, along with the finding of a significant correlation between focused attention and gestational age suggest that alerting is most severely impacted in the earliest born infants. Two other studies which included only moderately-to-late born preterm infants give support to this idea as they failed to detect a preterm disadvantage in focused attention (de Jong et al., 2015; Hodel et al., 2017). Hodel et al. (2017) measured focused attention during free play with toys at 9 months and de Jong et al. (2015) measured 'on task persistence' during a structured parent child interaction at 18 months. However, as neither of these studies included E/VPT groups, further work is needed to confirm associations with GA.

#### 3.3 | Standardized tests

A number of studies have used a variety of standardized tests to measure alerting. Six of these report significant group differences while eight do not (Table 2). Pitchford et al. (2011) found no group difference on the sustained attention subtest of the Leiter International Performance Scale-Revised (Leiter-R). They included a broad age range



**TABLE 2** Sample characteristics of alerting studies: Samples size, gestational age, age at time of testing, attention measure and main findings, organized by measurement type and variable

Authors	n	GA of preterm		Age at time of testing	Attention measures	Measurement types				Findings
		Preterm	Term			ET	O	ST	IR	
Reuner, Weinschenk, Pauen, and Pietz (2015)	93	38		7 months	Observation of looking behaviour		x			Focused attention: Preterm = term
Hodel et al. (2017)	71	67		9 months	Eye-tracking	x				Focusing: Preterm = term
de Jong, Verhoeven, and van Baar (2015)	123	101		12 months	Eye-tracking, observation and ECBQ	x	x		x	Alerting (ET): Preterm < term Focusing (O): Preterm = term Focusing (IR): Preterm = term
Downes, Kelly, Day, Marlow, and de Haan (2018)	19	21		12 months	Eye-tracking	x				Focusing: Preterm < term
Pitchford, Johnson, Scerif, and Marlow (2011)	22	30		2–5 years	Leiter-R			x		Sustained attention: Preterm = term
Geldof et al. (2013)	108	72		5 years	ANT			x		Alerting: Preterm = term
Pizzo et al. (2010)	25	25		5–6 years	ANT			x		Alerting: Preterm = term
Cserjesi et al. (2012)	248	130		7 years	TEA-Ch			x		Alerting: Preterm = term
de Kieviet, van Elburg, Lafeber, and Oosterlaan (2012)	66	66		7 years	ANT			x		Alerting: Preterm = term
Delane et al. (2017)	77	74		7 years	TEA-Ch			x		Sustained attention: Preterm = term
Murray et al. (2014)	198	70		7 years	TEA-Ch			x		Sustained attention: Preterm < term
Anderson et al. (2011)	198	173		8 years	TEA-Ch			x		Sustained attention: Preterm < term
Mulder, Pitchford, and Marlow (2011)	56	22		9–10 years	TEA-Ch			x		Sustained attention: Preterm = term

TABLE 2 (Continued)

Authors	n		GA of preterm group	Age at time of testing	Attention measures	Measurement types				Findings
	Preterm	Term				ET	O	ST	IR	
Lean, Melzer, Bora, Watts, and Woodward (2017)	110	113	VPT	12 years	TEA-Ch			x		Sustained attention: Preterm < term
Twilhaar, De Kieviet, Van Elburg, and Oosterlaan (2019)	55	61	VPT	13 years	ANT and SART			x		Alerting (reaction time): Preterm < term Alerting (accuracy) preterm = term Sustained attention: Preterm < term
Litt et al. (2012)	181	115	E/VPT/ELBW	14 years	CANTAB			x		Sustained attention: Preterm < term
Wilson-Ching et al. (2013)	288	115	EPT	17 years	TOVA			x		Sustained attention: Preterm = term

Note: 'Preterm < term' indicates significantly poorer performance in the preterm group regardless of the numerical direction of the score or magnitude of statistical significance.  
Abbreviations: ANT = Attention Network Task; CANTAB = Cambridge Neuropsychological Test Automated Battery; ECBQ = Early Childhood Behaviour Questionnaire;  
ELBW = Extremely Low Birth Weight (<1,000 g); EPT = Extremely Preterm (<28 weeks GA); ET = Eye-tracking; GA = Gestational Age; IR = Informant Report; Leiter-R = Leiter  
International Performance Scale-Revised; MLPT = Moderate to Late Preterm (32- <37 weeks GA); O = Observation; SART = Sustained Attention to Response Task; ST = Standardized  
Tests; TEA-Ch = Test of Everyday Attention for Children; TOVA = Test of Variables of Attention; VLBW = Very Low Birth Weight (<1,500 g); VPT = Very Preterm (28- <32 weeks GA).

of 2–5 years. Considering the rapid cognitive development that occurs during these early childhood years, neither the preterm nor term group is likely to comprise a homogeneous group, limiting any conclusions that can be drawn, especially given the relatively modest sample size (Table 2).

In a similar but narrower age group (5–6 years) Giordano et al. (2017) found differences in reaction time in a sustained attention subtest and in accuracy on a focused attention subtest of the Test of Attentional Performance for Children. Three studies report significant group differences in accuracy on the sustained attention subtest of the TEA-Ch (Anderson et al., 2011; Lean et al., 2017; Murray et al., 2014). In contrast, another three studies using the same task found no group differences in accuracy (Cserjesi et al., 2012; Delane et al., 2017; Mulder et al., 2011). Two of the former studies reported significantly higher levels of socioeconomic disadvantage in the preterm compared to the term group (Lean, Melzer, Bora, Watts, Woodward, et al., 2017; Murray et al., 2014). The third reported significantly higher numbers of children with a diagnosis of cerebral palsy in the preterm group (Anderson et al., 2011). The latter three studies do not report any such demographic differences, suggesting that group differences in sustained attention may have been driven by these confounding demographic factors rather than by prematurity.

An adapted version of the ANT, requiring a button press response to the appearance of a peripheral target in the absence of a cue, was used by de Kieviet et al. (2012). This task did not reveal significant group differences in alerting as measured by reaction time and nor did adapted versions of the same task (Geldof et al., 2013; Pizzo et al., 2010). However, group differences in reaction time but not accuracy on this task have been reported at 13 years (Twilhaar et al., 2019). The same study found group differences in both reaction time and accuracy on the Sustained Attention to Response Task (SART).

Litt et al. (2012) found significant differences in sustained attention between Extremely Low Birth Weight (ELBW) and Normal Birth Weight (NBW) adolescents at 14 years. However, when participants with neurosensory impairment and/or an IQ of <85 were excluded from analysis, significance dissipated. Another adolescent cohort study found no difference in alerting between groups (Wilson-Ching et al., 2013), also using an on screen button press task, the Test of Variables of Attention (TOVA). Differences in findings between studies might relate to the task type used, variable reported (e.g., reaction time vs accuracy), or age of participants. Disparities in findings between studies using the same task in similar age groups seem to reflect the demographic characteristics of the samples.

### 3.4 | Parent report

Studies including parent report measures which focus on the alerting network are scarce. De Jong and colleagues found no difference at 18 months in the attention focusing subscale of the Early Child Behaviour Questionnaire (ECBQ; de Jong et al., 2015).

In summary, alerting impairments have been reported during infancy, childhood, and early adolescence, but findings are extremely inconsistent, even when the same task is used in similar age groups. Findings from eye-tracking and observational studies suggest that infants born moderately to late preterm are less at risk for alerting impairments than those born extremely or very preterm. The majority of studies during childhood report no differences. However, several adolescent studies do report a preterm impairment and so problems do not simply dissipate with age.

## 4 | ORIENTING

Table 3 summarizes findings for studies that measured orienting, highlighting only key results in terms of whether there were statistically significant group differences, regardless of variable (e.g., accuracy, reaction time).

**TABLE 3** Sample characteristics of orienting studies: Samples size, gestational age, age at time of testing, attention measure and main findings, organized by measurement type and variable

Authors	n		GA of preterm group	Age at time of testing	Attention measures	Measurement types			
	Preterm	Term				ET	O	ST	IR
De Schuymer et al. (2012)	20	42	V/MLPT	4 and 6 months	Eye-tracking	x			Shifting (4 months): Preterm < term Shifting (6 months): Preterm = term
Ross-Sheehy, Perone, Macek, and Eschman (2017)	54	54	V/MLPT	5 and 10 months	Observation of looking behaviour		x		Orienting (5 months): Preterm < term Orienting (10 months): Preterm = term
Hodel et al. (2017)	71	67	MLPT	9 months	Eye-tracking	x			Shifting: Preterm = term
Downes et al. (2018)	19	21	E/VPT	12 months	Eye-tracking	x			Shifting: Preterm < term
de Jong et al. (2015)	123	101	MLPT	12, 18 and 24 months	Eye-tracking and ECBQ	x		x	Disengagement (ET): Preterm < term Shifting (IR): Preterm = term
Geldof et al. (2013)	108	72	VPT/VLBW	5 years	ANT			x	Orienting: Preterm = term
Giordano et al. (2017)	52	52	E/VPT	5–6 years	TAP-C			x	Shifting: Preterm < term
Pizzo et al. (2010)	25	25	VPT	5–6 years	ANT			x	Orienting: Preterm = term
de Kieviet et al. (2012)	66	66	E/VPT	7 years	ANT			x	Orienting: Preterm = term
Delane et al. (2017)	77	74	VPT	7 years	TEA-Ch			x	Selective attention: Preterm < term
Murray et al. (2014)	198	70	VPT	7 years	TEA-Ch			x	Selective attention: Preterm < term
Anderson et al. (2011)	198	173	EPT/ELBW	8 years	TEA-Ch			x	Selective attention (ST): Preterm < term Shifting (ST): Preterm < term
Mulder et al. (2011)	56	22	VPT	9–10 years	TEA-Ch			x	Selective attention: Preterm = term Shifting: Preterm < term
Lean, Melzer, Bora, Watts, and Woodward (2017)	110	113	VPT	12 years	TEA-Ch			x	Selective attention: Preterm = term Shifting: Preterm < term
Twilhaar et al. (2019)	55	61	VPT	13 years	ANT			x	Orienting: Preterm = term

Note: 'Preterm < term' indicates significantly poorer performance in the preterm group regardless of the numerical direction of the score or magnitude of statistical significance. Abbreviations: ANT = Attention Network Task; BRIEF = Behaviour Rating Inventory of Executive Function; ECBQ = Early Childhood Behaviour Questionnaire; ELBW = Extremely Low Birth Weight (<1,000 g); EPT = Extremely Preterm (<28 weeks GA); ET = Eye-tracking; GA = Gestational Age; IR = Informant Report; MLPT = Moderate to Late Preterm (32–<37 weeks GA); O = Observation; ST = Standardized Tests; TAP-C = Tests of Attentional Performance for Children; TEA-Ch = Test of Everyday Attention for Children; VLBW = Very Low Birth Weight (<1,500 g); VPT = Very Preterm (28–<32 weeks GA).

## 4.1 | Eye-tracking

Four eye-tracking studies of preterm infant orienting have been identified (Table 3). Two studies measuring attention shifting found no difference at 6 (De Schuymer et al., 2012) and 9 months (Hodel et al., 2017), although Hodel et al. do report a trend towards lower gestational age being associated with less frequent shifting in their MLPT sample. In the same sample as above, De Schuymer et al. found impaired shifting at 4 months in a competition/non-competition paradigm while Downes et al. (2018) found differences at 12 months in an attention control paradigm. Both of these studies included relatively low sample sizes (Table 3) and, in the case of De Schuymer et al. (2012), a particularly small sample size in the preterm group ( $n = 20$ ), raising the possibility that the study was insufficiently powered. If we assume the findings of Downes et al. (2018) to be legitimate, they should be considered in the context of GA. Mean GA for preterm infants in this study was 25.8 weeks while other studies included infants with GA of between 28 and 34 weeks, suggesting that shorter GA may be associated with vulnerability to switching impairments.

Only one study measured disengagement (which can be considered a more advanced orienting skill) and found differences at 12, 18, and 24 months (de Jong et al., 2015). Drawing only on the studies with large sample sizes, findings (based on only two studies) could be summarized as follows: shifting is intact at 9 months (Hodel et al., 2017), while disengagement is impaired at 12, 18, and 24 months (de Jong et al., 2015). More eye-tracking studies measuring both shifting and disengagement and their relationship to GA are needed to confirm these findings.

## 4.2 | Observational measures

Only one study of infant attention captured visual orienting using observational measures of looking behaviour. Ross-Sheehy et al. (2017) found reduced orienting speed in a spatial cueing task at 5 but not at 10 months, and less cue facilitation at 10 but not at 5 months, indicating the later emergence of covert orienting difficulties. Preterm infants displayed slower, but more accurate visual responses in all cue conditions at 5 months. Positive findings such as higher accuracy are often ascribed to an early orienting advantage which has been described in preterm infants up to 6 months of age and has been attributed to early extra-uterine visual stimulation (Butcher, Kalverboer, Geuze, & Stremmelaar, 2002; De Schuymer et al., 2012; Hunnius, de Wit, Vries, & von Hofsten, 2011), but if this was the explanation then speed of orienting would be expected to be preserved at 5 months. The authors provide an alternative explanation which implicates slower processing of the pre-cues in the incongruent condition. Slow processing of the cue may mean that a saccade has not been planned in advance of the target appearing and so allowing for more accurate direction of attention towards the target. This is in line with findings from studies reporting slower processing speed in preterm infants and children (Mulder et al., 2011; Rose, Feldman, & Jankowski, 2002). This raises uncertainty about the specificity of 'orienting' tasks to distinguish between orienting rather than processing speed and the importance of the distinction between speed and accuracy measurements.

## 4.3 | Standardized tests

Seven studies in children and adolescents report poorer performance in the preterm group on standardized assessments, while five report no difference. Three studies report significantly lower scores in the preterm groups on the shifting subtest from the Test of Everyday Attention for Children (TEA-Ch; Anderson et al., 2011; Lean, Melzer, Bora, Watts, Woodward, et al., 2017; Mulder et al., 2011). Similarly, Giordano et al. (2017) reported shifting differences on the Tests of Attentional Performance for Children (TAP). Three studies used the selective attention subtest from the TEA-Ch found impaired selective attention in the preterm groups (Anderson et al., 2011; Delane et al., 2017; Murray et al., 2014), while two studies found no group differences on the same task (Lean, Melzer, Bora, Watts, Woodward,

et al., 2017; Mulder et al., 2011). Inconsistent findings between studies using the same TEA-Ch subtest may be age related. Studies that did find differences included slightly younger children (7–8 years) than the studies finding no difference between groups on this task (9–12 years).

Four studies using an orienting test from a child version of the Attention Network Test (ANT) consistently found no significant difference in performance between preterm and full term groups (de Kieviet et al., 2012; Geldof et al., 2013; Pizzo et al., 2010; Twilhaar et al., 2019).

Disparities in findings between studies may reflect differences in the tasks used, and their reliance on varying attentional subcomponents and additional cognitive skills. For example, the selective attention task from the TEA-Ch is a pen and paper task requiring the child to locate and circle a target among several distractors. This task may also require inhibition of distractors, a process that relies on the executive attention system. The shifting subtest from the TEA-Ch requires children to count creatures along a trail and shift counting direction when prompted to do so by arrows. Numeracy skills are a prerequisite here and the type of 'shifting' required may be considered quite different to the shifting of visual attention implicated in the ANT (which measures reaction time in response to on-screen target preceded by a spatial cue) and may require additional attention control.

#### 4.4 | Parent report

Studies including parent report measures of attention orienting are scarce. Indeed, throughout the studies reviewed here, only two informant report measures differentiate between attention networks and only the Early Childhood Behaviour Questionnaire (ECBQ) has a specific measure of attention orienting. De Jong et al. (2015) found no significant difference on the attention shifting subscale of the caregiver report version of the ECBQ at 12, 18, or 24 months. Given that orienting differences in the same sample were detected using eye-tracking (see Section 4.1) this might suggest that parents are unable to detect subtle orienting differences at this age. This finding along with the lack of parent report measures which specifically measure attention orienting, suggests that, in pursuit of early markers of attention problems, we may need to focus on experimental measures, to detect differences of interest.

Overall, results from studies measuring attention orienting indicate deficits in this system in preterm populations but the specific manifestation of these deficits is complex and seems to vary widely depending on the measurement method and metric. Impairments in preterm participants during infancy are reported by studies using eye-tracking (de Jong et al., 2015; De Schuymer et al., 2012; Downes et al., 2018), but small sample sizes call into question the robustness of some of these findings. Longitudinal studies in older children and adults need to be carried out to determine whether these eye-tracking findings persists over time. One study using a parent report questionnaire reported intact orienting at 12, 18, and 24 months (de Jong et al., 2015). Results from standardized tests are opposing and may reflect differences between tasks. Only one recent observational study was identified, and findings from this study suggest that impairments reflect slower processing speed rather than orienting abilities (Ross-Sheehy et al., 2017).

### 5 | EXECUTIVE ATTENTION

Table 4 summarizes findings for studies that measured executive attention, highlighting only key results in terms of whether there were statistically significant group differences, regardless of variable (e.g., accuracy, reaction time).

#### 5.1 | Eye-tracking

To our knowledge, only two studies have examined executive attention using eye-tracking in preterm infants. No studies were found in children or adults. The first study measured the proportion of correct looks on a

**TABLE 4** Sample characteristics of executive attention studies: samples size, gestational age, age at time of testing, attention measure and main findings, organized by attention domain and measurement type

Authors	n	GA of preterm group		Age at time of testing	Attention measures	Measurement types				Findings
		Preterm	Term			ET	O	ST	IR	
Hodel et al. (2017)	71	67	MLPT	9 months	A not B task		x			Inhibition: Preterm = term
Downes et al. (2018)	19	21	E/VPT	12 months	Eye-tracking	x				Inhibition: Preterm = term
de Jong et al. (2015)	123	101	MLPT	18 months	Eye-tracking	x				Delayed response (ET): Preterm = term
Jaekel, Eryigit-Madzwamuse, and Wolke (2016)	281	277		20 months	Raisin game		x			Inhibition: Preterm < term
Baron, Erickson, Ahronovich, Baker, and Litman (2011)	60	90	E/VPT/ELBW	3 years	BRIEF-P				x	Inhibition: Preterm = term
Verkerk et al. (2016)	151	41	VPT	3 years	BRIEF-P				x	Inhibition: Preterm < term
O'Meagher, Norris, Kemp, and Anderson (2019)	82	49	E/VPT	4–5 years	BRIEF-P (parent report)				x	Inhibition: Preterm < term
O'Meagher et al. (2019)	105	46	E/VPT	4–5 years	BRIEF-P (teacher report)				x	Inhibition: Preterm < term
Geldof et al. (2013)	108	72	VPT/VLBW	5 years	ANT			x		Executive attention: Preterm < term
Pizzo et al. (2010)	25	25	VPT	5–6 years	ANT			x		Executive attention: Preterm < term
Cserjesi et al. (2012)	248	130		7 years	TEA-Ch			x		Inhibition: Preterm < term Attention control: Preterm < term
de Kieviet et al. (2012)	66	66	E/VPT	7 years	ANT			x		Executive attention: Preterm = term
Delane et al. (2017)	77	74	VPT	7 years	TEA-Ch			x		Divided attention: Preterm < term
Murray et al. (2014)	198	70	VPT	7 years	TEA-Ch			x		Inhibition: Preterm < term Divided attention: Preterm < term
Anderson et al. (2011)	198	173	EPT/ELBW	8 years	TEA-Ch & BRIEF (parent report)			x	x	Inhibition (IR): Preterm < term Inhibition (ST): Preterm = term Divided attention (ST): Preterm < term
Mulder et al. (2011)	56	22	VPT	9–10 years	TEA-Ch			x		Inhibition: Preterm < term

TABLE 4 (Continued)

Authors	n		GA of preterm group	Age at time of testing	Attention measures	Measurement types				Findings
	Preterm	Term				ET	O	ST	IR	
Lean, Melzer, Bora, Watts, and Woodward (2017)	110	113	VPT	12 years	TEA-Ch			x		Divided attention: Preterm < term
Twilhaar et al. (2019)	55	61	VPT	13 years	ANT			x		Executive attention: Preterm = term
Wilson-Ching et al. (2013)	288	115	EPT	17 years	TEA and BRIEF			x	x	Divided attention (ST): Preterm < term Inhibition (IR): Preterm < term
(Nosarti et al., 2019)	61	64	VPT	20–25 years	TAP			x		Inhibition: Preterm < term Divided attention: Preterm < term

Note: ‘Preterm < term’ indicates significantly poorer performance in the preterm group regardless of the numerical direction of the score or magnitude of statistical significance.  
Abbreviations: ANT = Attention Network Task; BRIEF-P = Behaviour Rating Inventory of Executive Function; ECBOQ = Early Childhood Behaviour Questionnaire; ELBW = Extremely Low Birth Weight (<1,000 g); EPT = Extremely Preterm (<28 weeks GA); ET = Eye-tracking; GA = Gestational Age; IR = Informant Report; MLPT = Moderate to Late Preterm (32–<37 weeks GA); O = Observation; Preschool Version; ST = Standardized Tests; TAP = Test of Attentional Performance; TEA-Ch = Test of Everyday Attention for Children; VLBW = Very Low Birth Weight (<1,500 g); VPT = Very Preterm (28–<32 weeks GA).



delayed response task at 18 months and found no difference between groups (de Jong et al., 2015). Although an indirect measure of executive attention, this task relies on similar anatomical regions to executive attention (i.e., the dorsolateral prefrontal cortex). The second study measured the ability of infants to inhibit looks towards a distractor stimulus in an attentional control paradigm at 12 months (Downes et al., 2018). They found that the preterm group were no more likely to make fixations to the distractor than the full term group (Downes et al., 2018). The executive attention network is the last to develop and undergoes rapid maturation over a 6-month period before the age of 2 years. As both of these studies (de Jong et al., 2015; Downes et al., 2018) measure executive attention before that age, the lack of difference between groups may reflect the fact that the executive network has not yet matured in either group. Future studies using eye-tracking in older toddlers and children would be beneficial.

## 5.2 | Observational measures

Jaekel et al. (2016) found that children who were born earlier had lower inhibitory control at 20 months as measured by performance in the Raisin Game. In this task, children are required to wait 60 seconds before eating a raisin which is placed in front of them. In contrast, Hodel et al. (2017) found no group differences in inhibitory control at 9 months on an A not B task, again reporting on the same MLPT sample discussed above in Sections 3.2 and 4.1. However, in this case, gestational age did predict poorer performance. Again, due to the relatively late development of executive skills, a lack of group differences is not surprising at this age.

## 5.3 | Standardized tests

Studies using standardized assessments of executive attention focus on adults, and children beyond pre-school age. Studies most often use tasks from the TEA-Ch, TAP, or ANT. Studies using subtests from the TEA-Ch to measure divided attention or inhibition consistently report poorer performance in the preterm group (Cserjesi et al., 2012; Delane et al., 2017; Lean, Melzer, Bora, Watts, & Woodward, 2017; Mulder et al., 2011; Murray et al., 2014; Wilson-Ching et al., 2013) with one exception, where impairments were reported in divided attention but not inhibition (Anderson et al., 2011).

Giordano et al. (2017) measured divided attention, distractibility, and flexibility using the child version of the TAP and found impairments in 5–6 year old preterm children. Nosarti et al. (2019) measured response inhibition and divided attention using subtests of the TAP in 20–25-year-old adults and found impairments in both.

Studies using the executive attention measure from the ANT (which measures inhibition of incongruent cues) provide less consistent results that largely contradict findings from the TEA-Ch and TAP. The majority of studies report no differences between preterm and term groups on reaction time (de Kieviet et al., 2012; Geldof et al., 2013; Twilhaar et al., 2019) or accuracy (de Kieviet et al., 2012; Twilhaar et al., 2019). In contrast, Pizzo et al. (2010) found slower reaction times in a relatively small sample of 5–6 year-old preterm children. Although they collected accuracy data, these were not reported. The larger age range, smaller sample size, and inconsistent reporting in this case suggests that findings from the studies reporting no differences may be more reliable. Only one study using the ANT reports impaired accuracy in the preterm group at 5 years (Geldof et al., 2013). Additional filters were applied to the data prior to analysis (removal of anticipatory and extremely slow responses) which may account for this difference.

If we rely on measures with the most consistent findings between studies (TEA-Ch and TAP), then findings largely support the existence of a preterm disadvantage on standardized tests of executive attention across childhood, adolescence, and adulthood.

## 5.4 | Parent report

Five studies were found which used parent report measures of executive attention (Anderson et al., 2011; Baron et al., 2011; O'Meagher et al., 2019; Verkerk et al., 2016; Wilson-Ching et al., 2013). Impairments were consistently reported for the preterm groups (Table 4). Baron et al. (2011) administered the Inhibit Scale of the preschool version of the BRIEF to parents of 3-year-old children. They found that parents of extremely low birth weight children rated them more highly (indicating more problem behaviours with inhibition) than did parents of children with normal birth weight. Verkerk et al. (2016) also reported differences at 3 years in very low birth weight compared to normal birth weight children on the BRIEF-P. Parents and teachers of preterm children rated them as having more problem behaviours on the child version of the same scale at 4–5 years (O'Meagher et al., 2019) and at 8 years (Anderson et al., 2011). As did parents of 17-year-old adolescents who were extremely preterm or extremely low birth weight at birth (Wilson-Ching et al., 2013). They were also more likely to rate their children within the clinical range on this scale (Wilson-Ching et al., 2013). Interestingly, when rating themselves on the same scale, the adolescents in the extremely preterm or extremely low birth weight group did not rate themselves as having significantly more problems than participants in the full-term group. Wilson-Ching et al. (2013) found that participants in the very preterm group had slower but no less accurate response inhibition and divided attention. This is in line with findings from the orienting literature reported in Section 3.2 and again raises the questions as to whether speed is an appropriate metric for the measurement of attention.

Again, results from studies measuring executive attention are conflicting, even when studies use the same standardized measures in similar age groups. Interpretation of infant eye-tracking studies is limited by the fact that executive attention abilities have yet to fully develop in either group. Findings from observational studies suggest that differences may arise in line with the timing of the development of the executive system, in the second year of life. Some studies using standardized assessments (TEA-Ch and TAP) suggest that these executive difficulties remain throughout the life course, while others, using the ANT provide a less consistent picture. While parents consistently report poorer inhibitory control in preterm children and adolescents, 17-year-olds who were born preterm do not rate themselves as having problems with inhibition. Executive attention is perhaps the most poorly defined of the three attention systems and overlaps with other cognitive domains, most notably, executive function, and processing speed. Thus, results may reflect the somewhat ambiguous nature of the language used to label tasks of executive attention and the concomitant difficulty in determining exactly what cognitive processes underpin performance on a particular task.

## 6 | LINKING ATTENTION NETWORKS

A small number of studies measure all three attention networks. These studies are important in understanding whether the conflicting findings discussed thus far represent differences in sample characteristics. Two studies use eye-tracking to assess alerting, orienting, and executive attention in 12-month-old (Downes et al., 2018) and 18-month-old (de Jong et al., 2015) preterm infants, with sample sizes  $n = 40$  and  $n = 224$  respectively. Both studies report impairments in alerting and orienting, but no group differences in executive attention (de Jong et al., 2015; Downes et al., 2018). Again, lack of differences in executive attention at this age is unsurprising. Despite detecting alerting differences using eye-tracking, De Jong et al. (2015) did not find group differences in alerting in the same sample during a toy exploration task. These findings suggest that eye-tracking may be able to pick up on subtle alerting deficits that cannot be ascertained from behavioural observation. Three studies used the Child ANT in children between 5 and 7 years of age and found no differences in orienting or alerting between groups (de Kieviet et al., 2012; Geldof et al., 2013; Pizzo et al., 2010). Two of these studies found executive attention impairments (Geldof et al., 2013; Pizzo et al., 2010) while the other did not (de Kieviet et al., 2012). This disparity may be attributed to age related differences as de Kieviet et al. (2012) included slightly older children than the other studies

(7 years compared to 5 years of age). However, this is not supported by questionnaire studies that do report executive attention difficulties across a similar range of ages (Anderson et al., 2011; O'Meagher et al., 2019; Section 5.4). Studies using the TEA-Ch reported more consistent findings of impaired orienting and executive attention in 7 and 10 year olds with sample sizes  $n = 268$  and  $n = 78$  respectively and no difference in alerting (Mulder et al., 2011; Murray et al., 2014). Anderson et al. (2011) found impairments in all three attention networks in a sample of 362 8-year olds using a combination of standardized tests and parent-report questionnaires, as did Giordano et al. (2017) using the Test of Attentional Performance for Children in 104 5–6 year olds. Both studies included children who were born extremely preterm (<27 weeks), while studies reporting intact alerting in childhood (Mulder et al., 2011; Murray et al., 2014) included children born very preterm (<32 weeks) only, suggesting that alerting in childhood is more likely to be impaired in children born at earlier gestational ages.

Studies linking attention networks suggest that the functioning of the attention networks in preterm children are influenced by gestational age and vary based on age at assessment. Disparities between studies remain and reflect the methodological challenges associated with measurement of attention in general.

## 7 | DISCUSSION

From the above review, the attentional profile of the preterm phenotype remains unclear. However, if conclusions are weighted towards studies with the most robust designs, deficits in the alerting network are most apparent in early life and again during adolescence and appear to be associated with lower gestational age at birth. Although evidence for alerting problems during childhood is less consistent, the possibility remains that this inconsistency represents a lack of sensitivity of the measurement methods used in this age group rather than a true absence of childhood alerting problems. Lack of eye-tracking studies and appropriate parent report measures for this age group lead to reliance on standardized assessments. Impairments in the executive attention network seem to emerge during childhood and continue into adulthood, potentially deriving from early-life disturbances in alerting and orienting. As executive attention emerges later in development, it is difficult to accurately assess in children of preschool age or younger and so it is unsurprising that differences have not been detected in younger children.

Due to inconsistencies arising from methodological limitations that will be discussed in more detail below, the exact manifestation of preterm orienting difficulties cannot be conclusively described. Reliability of findings from eye-tracking studies are constrained by small sample sizes, while a dearth of appropriate questionnaire measures limit conclusions that can be drawn from the small number of studies that do use these methods. Uncertainty over the competing cognitive skills that may underly various tasks (e.g., processing speed or executive skills vs. orienting) limit comparability between studies using various standardize tests and observational measures. For example, there are known associations between prematurity and slower processing speed (Anderson, 2014). For this reason, children born preterm are likely to perform poorly on orienting tasks with a speed or reaction time component.

### 7.1 | Measurement methods

Eye-tracking has been successful in identifying orienting and alerting deficits in infancy, which other measures have failed to consistently detect as children grow up. Longitudinal studies using adapted versions of the same tasks in infancy, childhood, adolescence, and adulthood would help to determine whether these deficits do indeed disappear, or if eye-tracking is simply more sensitive than tools more commonly used in older samples. That said, eye-tracking is not without its limitations. Vulnerability to data quality issues including accuracy, precision, and data loss are of particular concern and are more common in developmental research (Aslin, 2012; Hessels & Hooge, 2019). Greater amounts of missing data in infant and child samples necessitate large sample sizes to ensure sufficient data for the detection of meaningful effects. In addition, eye-tracking requires the participant to be alert and compliant;

presenting a challenge when working with infant populations, and particularly with preterm infants and children who are at known risk for ADHD as data can only be recorded if the participant is looking at the screen. Sitting in front of a screen for prolonged periods may be challenging for those with inattentive or hyperactive symptoms. Thus, it is possible that owing to the deficit under investigation, data will be missing for participants with the most pronounced impairment, resulting in increased risk of conclusions being drawn from a biased sample and potential underestimation of deficits.

In this context, parent report questionnaires go some way towards addressing the issue of the need for alert and compliant participants. Although a less direct measure, questionnaires are useful for longitudinal cohort studies as the same measure can be used across several time points with minimal participant burden, thus making it easier to obtain large sample sizes. Despite these advantages, questionnaire measures which discriminate between attention networks are scarce, as are studies testing agreement between those that do and other methods meaning that questions remain around what exactly is being measured.

More focus should be placed on collecting parent report and self-report questionnaire data as children grow older as findings reported above (Section 5.4) suggest they are not always in agreement. Lack of agreement between parent and child report measures may be accounted for by parent factors that might influence their perception of their child's behaviours such as maternal depression, parenting stress, and home environment (Brown, Weatherhol, & Burns, 2010; Joyner, Silver, & Stavinocha, 2009; McLuckie et al., 2018; Smith, 2007) and child factors such as age and assessment setting (Smith, 2007).

Standardized assessments are useful for developmental studies as they allow development to be charted in comparison to age-appropriate norms. However, it is important to note that investigators may choose whether to use corrected or chronological age when scoring normed assessments. Studies using chronological age are more likely to find a preterm disadvantage. There are a limited number of assessments of this nature appropriate for preschool age and evidence for the validity and utility of those available remains scarce (Mahone & Schneider, 2012). This limits the efficacy of these types of measures for the assessment of developmental trajectories.

## 7.2 | Future directions

Overall, findings from this review are largely in line with those of previous reviews which concluded that preterm infants and children are at risk for orienting, alerting, and executive attention problems but that findings are inconsistent (Mulder et al., 2009; van de Weijer-Bergsma et al., 2008). Mulder and colleagues similarly found age related and GA related effects and point to methodological differences between studies as an obstacle to delineating a clear and consistent picture. It is disappointing that another decade of study seems not to have been able to increase our certainty on this front. In an attempt to capture the preterm attentional profile in a way that is relevant to the contemporary population, this review was limited to studies published in the last 10 years. However, it is important to consider that more recent publications using data from older cohorts may have confounded these efforts. We have considered this in our summary of the literature but have not encountered any cases where differences in findings between studies which use similar methods in similar age groups can be accounted for by year of birth.

Uncertainty raised by this and previous reviews can likely be attributed (at least in part) to low sample sizes, publication bias, lack of pre-registration, and insufficient protocol harmonization (Frank et al., 2017). Future studies in this field must embrace open and collaborative practices to address these and other methodological issues before a well-defined picture of the preterm attention phenotype can be established. Large, longitudinal studies which use the same or similar age-adapted measures across time are necessary to determine the developmental trajectories of preterm attentional profiles.

Efforts to standardize measures and metrics between studies would improve replicability and reliability, as would improve standardization of the language used to describe attention networks and processes. Due to the complex and sometimes overlapping nature of cognitive functions, it is challenging to select tasks which are independent of

confounding deficits associated with prematurity. A lack of consensus around which attention or cognitive processes underpin specific tasks may contribute to inconsistencies in interpretation of results.

Few of the studies discussed in this review have examined the full repertoire of specific attentional domains, meaning that the conclusions drawn here are not exhaustive and may reflect methodological or demographic differences between samples. For example, limiting this review to include studies with a more sensitive cut off for prematurity may have yielded greater consensus. Consideration should also be given to the possibility that the inconsistencies raised by this review may reflect individual attentional differences underpinned by complex interactions between neurological, biological, or social mechanisms that were not accounted for here. For example gestational age, birth weight, medical risk, infant temperament, socioeconomic status, maternal psychological wellbeing, maternal interactive behaviours, and others have all been linked to attention development in preterm infants (see van de Weijer-Bergsma et al. (2008) for a review of biological and environmental factors). In addition, there is a growing body of literature indicating that altered white matter connectivity of the preterm brain is linked to impairments in attention (Loe, Lee, & Feldman, 2013; Murray et al., 2016; Nagy et al., 2003). Future research resolving specific tracts of interest and relating white matter microstructure of these pathways to specific attention domains would be of interest. However, another possibility is that integration of the three attention networks is impeded by alterations in whole-brain connectivity resulting in a global attention problem that cannot consistently be attributed to one or more specific networks.

## 8 | CONCLUSION

There is evidence that attention in preterm infants is indeed impaired. The most robust and consistent evidence points to deficits in alerting in infancy and adolescence, and in executive attention from early childhood onwards. Effective performance of these networks appears to decrease with lower gestational age at birth. Equivocal results from investigations of the orienting network mean that we do not rule out prematurity-related difficulties in this area too. Open questions include the extent to which early differences in orienting and alerting networks are maintained in childhood and adolescence, and whether these provide the developmental basis for later executive attention differences. Well-powered longitudinal studies, potentially combining data from multiple studies with harmonized protocols, using a range of measurement types consistently over time, and controlling for biological and social factors are needed. Considering the clinical implications of this work, a direct comparison of the preterm and ADHD cognitive, behavioural, and neurological phenotype is needed to elucidate the boundaries between the two and reveal the attention phenotype of preterm infants and how it relates to other aspects of development and cognition.

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## CONFLICT OF INTEREST

None.

## DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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